2012 Asia-Pacific International Symposium on Aerospace Technology
Nov. 13-15, Jeju, Korea

Automatic Ground Collision Avoidance System Design for Pre-Block 40 F-16 Configurations

Edward M Griffin[1], Russell M Turner[1], Shawn C Whitcomb[1], Donald E Swihart[2], James M Bier[2], Kerianne L Hobbs[2], Amy C Burns[2]

[1]*Lockheed Martin Aeronautics, Fort Worth, TX, USA*

[2]*Air Force Research Lab, WPAFB, OH, USA*

Abstract

The Air Force Research Laboratory (AFRL) with support from the Office of Secretary of Defense (OSD) has undertaken a program to develop the Automatic Ground Collision Avoidance System (Auto GCAS) to reduce the number of fighter aircraft lost due to Controlled Flight into Terrain (CFIT) accidents. Currently, automated control concepts, such as Auto GCAS, cannot be implemented onto early model F-16s with analog flight control systems. AFRL has initiated a new phase of the Auto GCAS program to find a technical solution that will enable the integration of Auto GCAS onto pre-Block 40 F16s. The project has developed an innovative and affordable solution where redundant digital processor modules are added to the analog flight control computer without affecting the existing analog modules resulting in a hybrid digital/analog flight control architecture. This architecture provides a technical path forward for incorporating advanced automated capabilities onto pre-Block 40 F-16s. This paper will provide a description of Auto GCAS, discuss the modifications required to integrate Auto GCAS onto F-16s with analog flight control systems, review the current status of the Analog Auto GCAS program and discuss other advanced automated capabilities that are enabled by the hybrid flight control architecture concept.

Keywords: Auto GCAS, Collision avoidance, Autopilot, Hybrid flight control computer

1. Introduction

CFIT accidents are the number one cause of United States Air Force (USAF) fighter aircraft fatalities and the number two cause of USAF fighter aircraft mishaps. These accidents account for 25 percent of USAF fighter aircraft destroyed over the past forty years. In order to protect pilots from CFIT accidents, there have been multiple different manual warning systems added to the F-16. These systems have utilized both visual and aural warnings. For these systems to be effective, they must initiate with sufficient time to allow the pilot to react to the warning and maneuver the aircraft. This has often led to a nuisance prone warning system that the pilot learns to ignore. Other problems with manual warning systems were that some of the warnings were missed because of task saturation, channeled attention, spatial disorientation or g-induced loss of consciousness. Total flying experience and recent flying experience were also looked at as ways to predict CFIT mishaps; however, it was determined they do not influence CFIT rates. Additional training did not prove to be effective in preventing CFIT mishaps. Therefore, it was determined that an automatic solution was necessary [1–3].

An automatic solution has the capability to activate after the pilot can no longer avoid the collision, recover the aircraft and quickly give control back to the pilot. The AFRL Automatic Collision Avoidance Technology (ACAT) program has developed an automatic solution called the Automatic Ground Collision Avoidance System (Auto GCAS) to protect pilots from CFIT accidents.

A business case was developed and it was determined that this technology would save the war-fighter billions of dollars, hundreds of aircraft and hundreds of pilot lives by putting this technology on-board platforms with digital flight control computers such as the F-16, F-22 and F-35. The digital version of Auto GCAS was flight tested and demonstrated to effectively prevent all historic gear up F-16 CFIT accidents without adversely affecting the operational capabilities of the aircraft. As a result, Auto GCAS is currently being transitioned to the USAF digital F-16s and will be operational in 2014.

The current focus of the ACAT team is to develop this technology for F-16s with analog flight control computers (pre-Block 40 aircraft). There are approximately 1400 F-16s with analog flight control computers that could benefit from this technology. This number includes both USAF F-16s (400) along with foreign government F-16s (1000). The business case for integrating Auto GCAS onto the analog F-16s is dependent on several factors including fleet size, annual flight hours, CFIT accident rate and how long the aircraft are expected to remain in service. Figure 1 shows the estimated number of US analog F-16s lost per year without Auto GCAS as a function of fleet size. Figure 2 shows the number of years required to generate a positive return on investment (ROI) if Auto GCAS was integrated onto the fleet. This is also shown as a function

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
NOV 2012	**N/A**	**-**

4. TITLE AND SUBTITLE
Automatic Ground Collision Avoidance System Design for Pre-Block 40 F-16 Configurations

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lockheed Martin Aeronautics, Fort Worth, TX, USA

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA578411. Asia-Pacific International Symposium on Aerospace Technology (APISAT 2012) Held in Jeju, South Korea on November 13-15, 2012. AOARD-CSP-131003

14. ABSTRACT
The Air Force Research Laboratory (AFRL) with support from the Office of Secretary of Defense (OSD) has undertaken a program to develop the Automatic Ground Collision Avoidance System (Auto GCAS) to reduce the number of fighter aircraft lost due to Controlled Flight into Terrain (CFIT) accidents. Currently, automated control concepts, such as Auto GCAS, cannot be implemented onto early model F-16s with analog flight control systems. AFRL has initiated a new phase of the Auto GCAS program to find a technical solution that will enable the integration of Auto GCAS onto pre-Block 40 F16s. The project has developed an innovative and affordable solution where redundant digital processor modules are added to the analog flight control computer without affecting the existing analog modules resulting in a hybrid digital/analog flight control architecture. This architecture provides a technical path forward for incorporating advanced automated capabilities onto pre-Block 40 F-16s. This paper will provide a description of Auto GCAS, discuss the modifications required to integrate Auto GCAS onto F-16s with analog flight control systems, review the current status of the Analog Auto GCAS program and discuss other advanced automated capabilities that are enabled by the hybrid flight control architecture concept.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**7**	

of fleet size. The data is based on 300 flight hours per year per aircraft. A positive ROI is yielded when the affected fleet remains in operation from 2.5 to 5.5 years after modification, depending upon the number of modified aircraft.

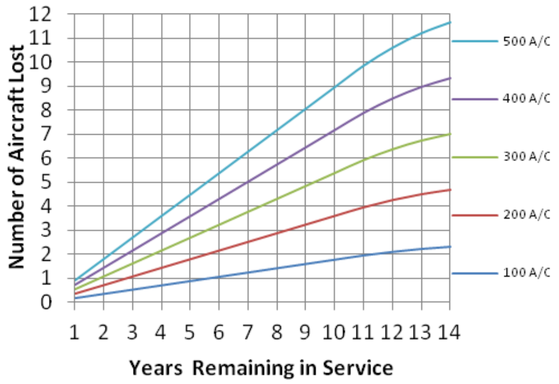
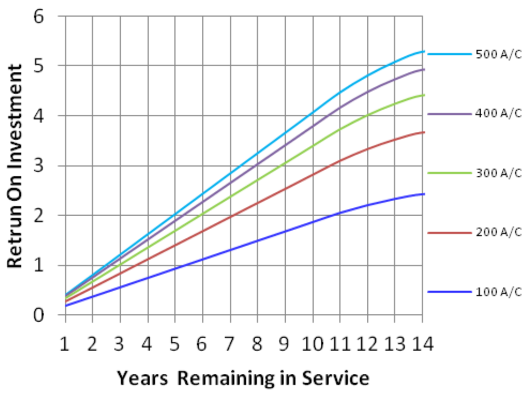


Fig. 1 Estimated CFIT Losses

Fig. 2 Expected Return on Investment



Based on this data, AFRL believes there is a strong business case for the development and integration of Auto GCAS onto the analog F-16 aircraft.

2. Automatic Ground Collision Avoidance System (Auto GCAS)

Auto GCAS evolved over multiple programs during a 25 year period. Initial development was carried out on the Advanced Fighter Technologies Integration F-16 (AFTI/F-16) as a safety measure enabling flight test of the Automated Maneuvering Attack System research project in the mid 1980s. This implementation utilized the radar altimeter to determine the location of the ground directly below the aircraft but was unable to detect obstacles in front of the aircraft. In 1992, Auto GCAS was upgraded to utilize Digital Terrain Elevation Data (DTED) instead of the radar altimeters. DTED is effectively a digital topographic map. Given the aircraft's GPS location and velocity, the system could use DTED to predict impact with the ground independent of the orientation of the aircraft. In 1997, a joint program was initiated between the United States and Sweden with the goal of turning Auto GCAS into a system suitable for implementation on the wider F-16 and SAAB Gripen fleets. It was demonstrated on a fleet F-16 in 1998 [4, 5]. Unfortunately, aircraft avionics and flight control system hardware upgrades required for the system were prohibitively expensive at the time. However between 2000 and 2005 significant upgrades occurred to the USAF F-16 fleet. With these upgrades, it became possible to implement Auto GCAS without changing the aircraft's hardware. This led to the ACAT digital Auto GCAS program (2007-2010) [6] which updated the 1998 design by integrating the system on the current digital F-16 configuration and performing validation flight testing of the system described in this paper.

2.1 Auto GCAS Requirements

Auto GCAS was designed based on three top-level requirements, from which all other requirements were derived: 1) Do No Harm – The system shall not cause an accident; 2) Do Not Interfere – The system shall not prevent the pilot from executing their mission; 3) Prevent Collisions – The system shall prevent collisions with the ground.

These requirements are listed in order of precedence. In cases where one requirement interferes with another, the higher-priority requirement overrides the lower priority requirement. Thus, if attempting to prevent collisions might cause harm to the aircraft or prevent the pilot from executing their mission, the system is forced into an inactive state.

2.2 Auto GCAS Architecture

The Auto GCAS Architecture is depicted in Figure 3. Auto GCAS uses a high precision navigation solution superimposed over DTED to determine the location of the aircraft in relation to the terrain. This allows the system to interrogate the terrain, in any direction, several miles from the aircraft. The Auto GCAS algorithm then determines the terrain in Terrain Map Scanning based on the current state of the aircraft. The algorithms then compute the aircraft's trajectory in the Trajectory Prediction Algorithm (TPA). When the data indicates that the aircraft trajectory will intercept the terrain of interest, an automatic recovery maneuver is commanded. The Auto GCAS architecture was designed to be easily transitioned to other platforms by modularizing the system elements. This allows system integrators the freedom to partition the system elements differently for each specific platform.

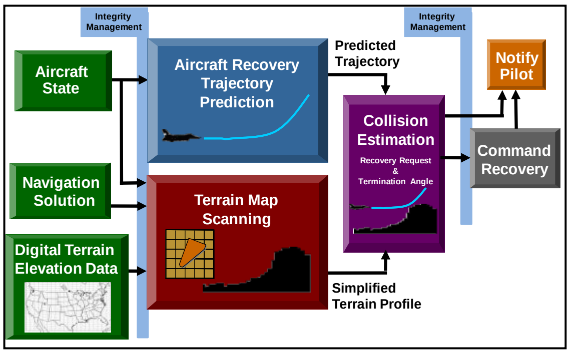


Fig. 3 Auto GCAS Modular System Architecture

The Auto GCAS algorithm consists of four primary components: 1) Trajectory Prediction Algorithm (TPA); 2) Terrain Scanning Algorithm; 3) Collision Estimation Routine; and 4) Flight Control Coupler.

The TPA predicts the aircraft's trajectory during an automatic recovery, or "flyup." The TPA predicts the trajectory of the aircraft for a recovery maneuver, consisting of a roll to wings-level followed by a 5 g pull-up. The TPA does a prediction each frame it is called based on the current aircraft flight condition.

The Terrain Scanning Algorithm reduces the DTED map to a two-dimensional profile of the terrain in front of the aircraft. It starts by choosing an area in which it "scans" the map for terrain data. This scan area is typically fan-shaped, with the narrow end of the fan rooted right in front of the aircraft. The exact shape of the scan area will change based on the current airspeed, turn rate, and flight path angle. The orientation of the scan pattern on the DTED map is determined by the aircraft's GPS position and heading. Figure 4 illustrates some example scan shapes. Terrain data inside the scan pattern is retained and all other terrain data is ignored. A non-turning aircraft will scan the terrain in a symmetric fan shape. A turning aircraft will scan the terrain in an asymmetric fan that looks into the turn. An aircraft in a steep dive will scan the terrain in an octagonal pattern to account for any direction in which the aircraft could exit the dive. The scan pattern is divided into "bins" perpendicular to the flight path. The highest terrain point in each bin is taken and used to construct a 2-D terrain profile along the axis of movement.

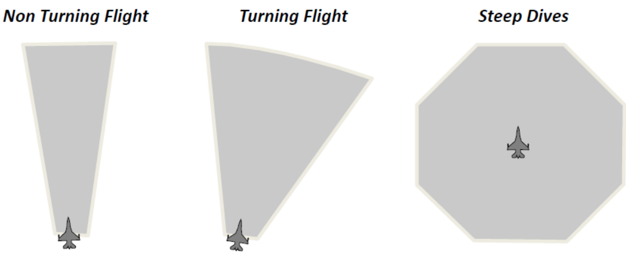


Fig. 4 Terrain Scan Pattern Examples

The Collision Estimation Routine superimposes the trajectory predicted by the TPA onto the 2-D terrain profile, Figure 5. In effect, the trajectory is projected in front of the aircraft. If any portion of the trajectory touches any point of the terrain profile, then the collision estimation routine requests a flyup from the flight control system.

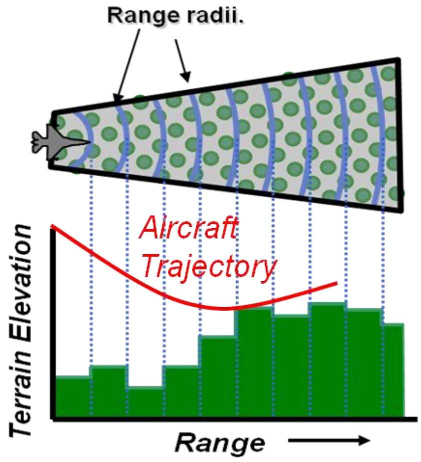


Fig. 5 Auto GCAS Collision Estimation Routine

Finally, a flight control coupler, or outer loop flight control laws, that responds to a request from the collision estimation routine and commands the aircraft to perform the automatic recovery maneuver (roll to wings level followed by a pull-up). The flight control coupler must be designed and tested to safety of flight certification standards because of its flight critical function. This means that the flight control coupler must be hosted in a flight critical, redundant environment. However, the system designer may desire to partition some of the other system elements in non-redundant avionics systems. To facilitate this, the Auto GCAS team implemented System Wide Integrity Monitors (SWIM) within the flight control system to monitor the health of the Auto GCAS system components to determine if it is safe to perform an automatic recovery maneuver.

3. Hybrid Flight Control Computer Concept

The concept of the hybrid flight control computer is to integrate a digital processor to work along with the legacy analog hardware functions without affecting the integrity of the legacy system and provide an interface to other avionics subsystems on the aircraft. This concept provides a bridge to incorporate advanced capabilities such as Auto GCAS.

There are three primary flight control system requirements related to the implementation of Auto GCAS: 1) Interface with avionics subsystems so the Auto GCAS algorithm can communicate with the flight controls; 2) System integrity software which monitors the health of any non-redundant system elements; and 3) Flight control

software that will command an automatic recovery. Flight control logic is divided into two primary elements; inner loop and outer loop. The inner loop flight control logic is responsible for maintaining the desired stability level of the aircraft and commanding the deflection of the aircraft control surfaces. Automated maneuvers, such as the Auto GCAS recovery maneuver, are examples of outer loop functions.

3.1 Analog Flight Control Architecture

The most significant challenge in transitioning Auto GCAS to the pre-Block 40 F-16's is integrating the flight control functions within the analog flight control computer (FLCC). Unlike modern, digital flight control computers, the FLCC installed on pre-Block 40 F-16's is a quad-redundant analog design. The FLCC receives the pilot's stick and pedal input signals, along with additional aircraft input signals (e.g., pitch rate, normal acceleration, roll and yaw rates, side acceleration, angle of attack [AOA], impact pressure over static pressure [Qc/Ps]), which are processed (filtered, shaped, summed, gain adjusted and amplified) by analog circuitry to determine the commanded pitch, roll and yaw adjustments required for controlled flight. Outputs of the FLCC drive integrated servo actuators (ISAs), which in turn control the position of the aircraft's control surfaces.

The analog FLCC had no digital processors and therefore no software that could be modified to host the Auto GCAS flight control functions. Modifications to the legacy analog circuitry were ruled out due to the complexity of the modification and the subsequent safety of flight regression testing, both simulated and in flight, that would be required to certify the FLCC for flight. The team also investigated replacing the analog FLCC with an updated digital flight control computer but this aircraft modification was well outside the available funding for a modification program for a legacy platform. A cost effective solution that took safety of flight certification requirements into account was required to move forward with the program.

3.2 Hybrid Flight Control Computer (HFLCC)

The ACAT team's approach for implementing the Auto GCAS flight control functions on the analog F-16 was to modify the existing analog FLCC by incorporating digital processor modules within spare slots of the FLCC. This resulted in a hybrid flight control computer that consisted of legacy inner loop control laws hosted on legacy analog circuit cards and Auto GCAS functions hosted on new digital processor modules. It provided a cost effective path forward for integrating Auto GCAS without impacting the existing inner loop flight control laws. This limited the flight safety concerns for certification of the new Auto GCAS software and the interface between the digital and analog components.

A picture of the analog FLCC, with the top cover removed, is shown in Figure 6. The analog circuitry is housed in an aluminum chassis which is partitioned into four redundant branches. Each branch is populated with five analog circuit cards and a sixth, spare slot is provided for future expansion. In addition, each branch features a power supply which receives AC input power and generates DC voltages for use by the analog circuitry as well as by external equipment. Five circular connectors mounted on the front of the chassis provide the mating interfaces to the aircraft wiring.

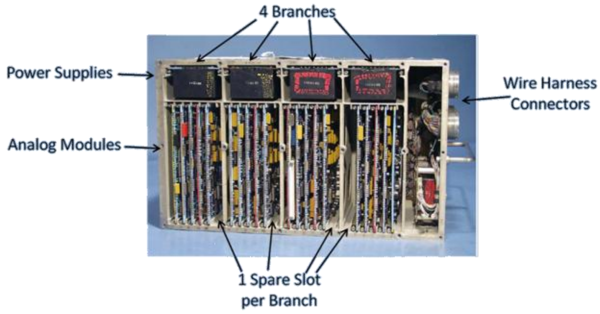


Fig 6 F-16 Analog Flight Control Computer

The Hybrid FLCC design consisted of the following modifications:

- Installing a new, digital processor module in the spare slot of each branch.
- Replacing the existing motherboard with a re-designed version.
- Adding cross channel data links (CCDL) between the 4 new digital processor modules for failure management.
- Adding jumper wires and changing component values on the power supplies.
- Adding two new circular connectors to the front of the chassis.
- Adding the FLCC to the existing 1553 avionics MUX.
- Creating a new software build for the digital processor modules to host the Auto GCAS flight control functions.

The flight control coupler requires the ability to send pitch, roll, and yaw commands to the inner loop flight control functions and at times cancel out pilot inputs. In the F-16 digital flight control computer, outer loop functions, such as the Auto GCAS Coupler, are hosted within the auto pilot software. This allows the Auto GCAS coupler to send pitch, roll, and yaw commands directly to the inner loop command blender. In pre-block 40 F-16s the auto pilot is hosted outside of the FLCC and the flight controls limit the auto pilot command authority before sending it to the inner loop command blender. To work around this in the hybrid design, coupler commands are summed with the pilot stick and pedal inputs prior to entering the inner loop control laws. A simplified diagram of this concept is shown in Figure 7. This

concept also meant that no changes would be required to the legacy analog modules hosting the inner loop control laws. All modifications to the FLCC would be up stream of the existing analog modules limiting flight safety concerns for certification of the new digital elements and their interface with the existing analog circuitry.

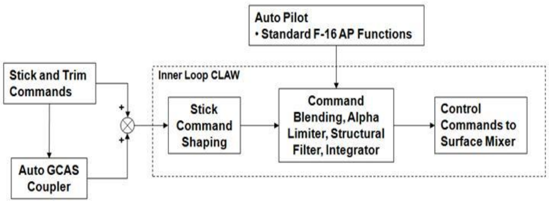


Fig. 7 HFLCC Outer Loop Control Law Integration Concept

3.3 Analog Auto GCAS Development Status

As of the writing of this paper, two analog flight control computers have been modified to the HFLCC configuration, Figure 8. One HFLCC has undergone initial design verification environmental testing including electromagnetic interference testing, vibration testing, and temperature and altitude testing. The HFLCC has passed each of these initial safety of flight test requirements. The second HFLCC has been integrated into Lockheed Martin's F-16 Handling Qualities Simulator to support software development and system test. To date, the HFLCC has been integrated with the digital F-16 avionics facilitating testing of Auto GCAS with the HFLCC hardware in the loop.

Fig. 8 Completed HFLCC

Under the current AFRL program, three additional analog flight control computers will be modified to the updated HFLCC configuration and undergo unit and system level safety of flight testing required to support a safety of flight certification effort.

4. Automated Capabilities Enabled by the HFLCC

The HFLCC is an enabling technology for the pre-Block 40 F-16 fleets, facilitating the development and integration of advanced automated capabilities that were previously unavailable to these aircraft. This section will explore several candidate technologies for future study and discuss preliminary integration strategies utilizing the HFLCC architecture.

4.1 Automatic Aircraft Collision Avoidance

Auto ACAS is being designed to prevent mid-air collisions of fighter aircraft during Basic Fighter Maneuver (BFM) and Air Combat Maneuver (ACM) training without adversely effecting mission performance. Mid-air collisions are among the leading causes of fighter mishap losses, accounting for approximately 25 percent of all US F-16 operational related flight mishaps. Auto ACAS has been re-designed [7] and is now intended for use in the highly dynamic fighter air combat training environment, where midair collisions are most likely to occur.

Integration of Auto ACAS onto the pre-block 40 F-16 fleets would leverage the Block 50 design. The existing avionics infrastructure on the Mid Life Upgrade (MLU) F-16s will support Auto ACAS operation. The existing Auto ACAS control laws and SWIM functions from the digital F-16 implementation can be re-hosted in the HFLCC architecture similar to the Auto GCAS implementation.

4.2 Automatic Terrain Following

Automatic Terrain Following (Auto TF) has been integrated on later Block F-16 aircraft (Block 40/50). This system provides the pilot with the ability to fly at low altitude, at night or in poor visibility conditions. The F-16 Auto TF system consists of a LANTIRN navigation pod (AAQ-13), pilot interfaces via the Heads Up Display (HUD) and Multi-Function Display (MFD) as well as automated pitch commands via the digital flight control computer. Pre-Block 40 F-16's that have been updated to the Mid-Life Upgrade (MLU) configuration have the avionics capability to support Auto TF. The HFLCC enables the integration of the required control laws and system wide integrity monitors to automate the vertical acceleration commands from the LANTIRN navigation pod.

The F-16 TF system has three primary modes of operation: Manual TF, Auto TF and Blended TF. During Manual TF operation the pilot receives flight path cueing in the HUD to maintain a selected altitude above ground level (AGL). During Auto TF operation the flight control computer uses the vertical acceleration commands generated in the LANTIRN pod to maneuver the aircraft to maintain the selected AGL. During Blended TF operation the autopilot is engaged to hold a specific barometric altitude. If the LANTIRN pod detects the aircraft violating the selected minimum AGL the system will automatically maneuver the aircraft to maintain the minimum AGL until the terrain has dropped away. Once the terrain drops away, the system returns to the altitude hold autopilot.

Integration of the Auto TF system onto the pre-block 40 F-16 fleets would leverage the Block 40/50 design. The existing avionics infrastructure on the MLU aircraft will support Auto TF operation. Two F-16 Block 40/50 cockpit switches (Advanced Mode and Manual TF Flyup) that support Auto TF operation are not available in early block aircraft. This will require either existing switches be repurposed or additional mode logic be incorporated onto the existing Auto TF MFD screens. Additionally, a single discrete voltage wire from the Left Hard Point station of the engine inlet to the HFLCC is required to support Auto TF SWIM. The existing Auto TF control laws and SWIM software from the digital F-16 implementation can be re-hosted in the HFLCC.

In addition to re-hosting the Auto TF capability on the pre-block 40 F-16's there is also an opportunity to investigate the integration of Digital Terrain Elevation Data (DTED) with the radar solution from the LANTIRN pod to improve the fidelity of the terrain solution and limit the usage of the terrain following radar in operational environments.

4.3 Auto Land

Auto GCAS provides ground collision avoidance protection while the landing gear is up. Once the landing gear is down, the system enters a stand-by mode inhibiting automatic maneuvering. Several F-16 operators have requested additional collision avoidance protection during the landing phase of flight. The majority of historical gear down incidents involved a failure to maintain proper glide path. Initial investigations into mechanizing an Auto GCAS system during landing required the ability to: 1) Determine if the aircraft is not properly aligned with the runway; 2) Perform a go around maneuver if the aircraft is not aligned with the runway. The results of the gear down Auto GCAS study indicated that a recovery maneuver based solution would be difficult to integrate and have significant potential to encounter nuisance recoveries during landing. A better solution to reduce landing related incidents is to provide selectable levels of automation during landing to aid the pilot at night or in poor weather conditions.

The proposed F-16 Auto Land system concept incorporates three modes of operation: HUD Cueing, Glide Slope Capture and Full Auto Land. The HUD Cueing mode would provide flight path and throttle position cueing in the HUD to acquire and capture the glide slope. Cues would continue through flare maneuver to touch down. The Glide Slope Capture mode would automate pitch, roll and yaw commands to acquire the glide slope and execute the flare maneuver. The pilot would still be responsible for energy management via throttle inputs with the system providing throttle cueing in the HUD. The Full Auto Land mode would incorporate an auto throttle capability to automate energy management during landing. The integration of auto throttle would be an additional aircraft modification outside of the current HFLCC upgrade.

The F-16 Auto Land system would incorporate several levels of system operation based on system health. These levels of operation would roughly correlate to the Instrument Landing System operational categories (Failed, Category I, Category II, Category III). Failed indicates that the system health has degraded to the point where the Auto Land functions cannot be performed. Category I indicates operation down to ~ 200 ft AGL, Category II indicates operation down to ~ 100 ft AGL and Category III indicates operation to landing. As system health degrades, the operational capability would automatically transition to Failed depending on the nature and timing of the failure. The status of the Auto Land system and available Auto Land capability would be provided to the pilot via HUD and MFD indications.

Integration of Auto Land onto the pre-block 40 F-16 fleets would utilize avionics and HFLCC elements. Pilot vehicle interfaces and airfield steer points would be incorporated via the avionics systems. The logic related to calculating the pitch rate and roll rate commands required to capture and maintain the glide slope as well as the outer loop control logic would be hosted in the HFLCC.

4.4 Departure Prevention Logic

The F-16 Block 40/50 programs implemented several features within the Digital Flight Control System (DFLCS) to improve the F-16 departure prevention characteristics. The HFLCC provides a mechanism to limit control inputs or command control inputs under specific flight controls. Several departure prevention features utilize this type of limited or controlling logic. The following is a list of departure prevention capabilities that could be integrated into pre-Block 40 F-16's via the HFLCC flight control software.

4.4.1 Angle of Attack (AoA) Limiter Update

The DFLCS AoA limiter was modified to minimize the overshoot of the AoA during maximum pitch command maneuvers at slower speeds. This modification provided protection against longitudinal departures for pitch sensitive loadings and directional departures for loadings with low static directional stability at high AoA. This functionality could be implemented in the HFLCC architecture through the introduction of a pitch stick command reduction as a function of washed out AoA. This update would emulate the AoA washout path implemented with the AoA limiter function currently in the DFLCS. The washout term would only be active at angles of attack above 20 degrees and would be switched

out with negative pitch stick inputs. This would improve AoA limiter performance without negatively impacting nose down recovery.

4.4.2 Inverted Anti-Spin Update

Inverted anti-spin logic was implemented within the DFLCS to automatically arrest yaw rate while in inverted deep stalls. This is currently performed by the pilot using the rudder pedals. However, when the aircraft is inverted, pilot disorientation may make it difficult for the pilot to command the pedals in the right direction to oppose the spin, and therefore may prolong the stall recovery. This implementation incorporates a cut-out of the primary rudder command paths and activates the proper rudder deflection while inverted to arrest the yaw rate. The command path cut-out switches require that the Manual Pilot Override (MPO) switch be depressed in addition to flight conditions indicating that an inverted departure exists. The MPO switch is available to the HFLCC processor so these functions can be implemented within the current HFLCC architecture.

4.4.3 Rudder Command Reduction at High Speed

The rudder command reduction at high speeds was implemented into the DFLCS primarily for the Foreign Military Sales (FMS) Block 50/52 F-16's that are capable of carrying conformal fuel tanks (CFT's). The modification was expanded to include non-CFT configurations to eliminate the need for pilot observed rudder command limits at high speeds. This update simply consists of the rudder command path gain that is scheduled as a function of airspeed. The rudder command path gain can be integrated into the existing HFLCC architecture to provide the equivalent functionality for the pre Block 40 F-16's.

5. Conclusions

The AFRL program has developed an innovative, cost effective approach for adding new technology to early Block F-16s. The development of the hybrid analog/digital flight control architecture overcomes the lack of a high authority autopilot needed for advanced automatic capabilities. In addition, it provides a means for integrity monitoring to be accomplished for such high authority applications thereby insuring safety for flight critical functions that use non-redundant subsystem information. This Hybrid Flight Control Computer has created a viable path forward for F-16s with analog FLCCs to implement Auto GCAS, Auto ACAS, Auto TF, Auto Land, and improved departure prevention. It will essentially eliminate controlled flight into terrain, enable all weather landings, and add enhanced departure prevention to the early Block F-16s.

The design was accomplished without altering the analog computer cards that provide inner loop control. In this way it averted the extensive re-certification tasks associated with such inner loop alterations. This development is a significant advancement for F-16s with analog flight control systems. It provides the means to incorporate any number of advanced capabilities to the aircraft beyond those discussed in this paper.

Acknowledgment

None.

References

[1] Burns, A., Hobbs, K., Bier, J., and Whitcomb, S., "Auto GCAS for analog flight control system", NATO SET-168 Symposium, Izmir, Turkey, 2012.

[2] Burns, A., Harper, D., Barfield, A. F., Whitcomb, S., and Jurusik, B., "Auto GCAS for analog flight control system", 30th Digital Avionics Systems Conference, Seattle, Washington, USA, 2011.

[3] Swihart, D., "Automatic Ground Collision Avoidance System (Auto GCAS)", ICS 09, 13th World Scientific and Engineering Academy and Society International Conference on Systems, Rodos Island, Greece, 2009.

[4] Swihart D., Barfield A., Brannstrom B., Cawood M., Turner R., and Lovgren J., "Results of a joint US/Swedish Auto Ground Collision Avoidance System program", 21st Congress of International Council of the Aeronautical Sciences (ICAS), Melbourne, Australia, 1998.

[5] Swihart, D., "Joint development of an Auto Ground Collision Avoidance System", 4th Saint Petersburg International Conference on Integrated Navigation Systems, St Petersburg, Russia, 1997.

[6] Swihart, D., Barfield, A., Griffin, E., Lehmann, R., and Whitcomb, S., "Design, Integration and Flight Test of an Automatic Ground Collision Avoidance System", 17th Saint Petersburg International Conference on Integrated Navigation Systems, St Petersburg, Russia, 2010.

[7] Turner, R., Lehmann, R., Wadley, J.; Kidd, D., Swihart, D., Bier, J., Hobbs, K., "Automatic Aircraft Collision Avoidance algorithm design for fighter aircraft", 2012 Asia-Pacific International Symposium on Aerospace Technology, Jehu, Korea, 2012.